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Near-infrared Spectroscopy System for Determining Brain Hemoglobin Level

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***Abstract*—Traumatic brain injury (TBI) usually results from brain shaking or impact. It can affect the normal function of the brain and even cause people become disabled and death. However, there is lack of studies for the physiological changes of humans or animals under brain injury. In order to obtain the information of physiological state change, we designed and enforced a non-invasive, wireless multi-channel near-infrared spectroscopy (NIRS) for monitoring the concentration change of oxy-hemoglobin (HbO_2), deoxy-hemoglobin (HbR) and total-hemoglobin (HbT) continuously during and after TBI. The experimental results indicated that the concentration change of HbO_2 and HbT is significantly related to the impact strength and infarction volume. Thus, this system is easily used and stable for TBI study.**

I. Introduction

Traumatic brain injury (TBI), usually results from brain shaking or impact, and affects the normal function of the brain. It causes people become disabled and at worst die. About 1.5 million American people endure TBI annually [1], and the financial burden for TBI was more than 50 billion U.S.D. [2]. After TBI, with the increment of their intracranial pressure (ICP), there have a high risk of hypoxemia or edema in brain, and have 30% mortality in the first three days [3]. It also causes the death due to the lack of timely examination and treatment [4].

The way of monitoring TBI is usually using intracranial pressure monitoring. However, its invasive measurement may cause brain hemorrhage and infection [5]. Recently, there are some noninvasive ways for inspecting TBI. Magnetic resonance imaging (MRI), computer tomography (CT) and positron emission tomography (PET) are used [6][7]. MRI using no ionizing radiation is safest. However, its cost is also the most expensive and its temporal resolution is poorer than CT [8]. Radioactive substance is needed as using CT and PET. Thus, all of them are unsuitable for long-term monitoring.

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Recently, near infrared spectroscopy (NIRS) were widely developed for cerebral science [9]. Red and near infrared light are used to penetrate through the brain, and their variation of relative optical transparency can directly reflect the information of relative concentration changes of HbO_2 and HbR, which are also associated with cerebral blood flow as well as oxygen metabolism. Thus, NIRS has more potential for detecting focal cerebral ischemia [10], hemorrhage [11], and post-injury cognitive functions [12].

In this study, a wireless multi-channel NIRS system was developed for real-time monitoring the change of HbR, HbO_2, and total-hemoglobin (HbT) concentrations during and after TBI. In addition, the information about the change of cerebral blood flow (CBF) was obtained by a laser Doppler flowmetry (LDF).This method was usually used to assist in investigating the change of the physiological state under different impact attacks.

II. Materials and Methods

A. Design of wireless multi-channel near-infrared spectroscopy system

Figure 1 is the system architecture from this study. (a).It contains a wireless signal acquisition module, an optical probe, and a host system. The optical probe contains dual light-emitting diodes (LED) and photodiodes (PD), used to supply the red and infrared light sources and transfer the intensity of diffusely reflective light into current respectively. We designed a wireless signal acquisition module to drive the light sources, and acquire the information of diffusely reflective light received by the photodiodes. And a commercial laptop is used as the platform of the host system. The operating system used in this platform is Windows 7. The real-time monitoring program developed by Microsoft Visual C# is designed to compute the real-time HbO_2 and HbR concentrations.

Due to the scattering and absorbing properties of the different structures in the tissue, only some light passes through the tissue as light emitting into the biological tissue [13].In this study, $\Delta[HbO2]$ and $[\Delta HbR]$ indicate the concentration changes of HbO2 and HbR separately, and $\Delta[HbT]$ means the concentration change of total-hemoglobin, which can be calculated by

$$\Delta[HbT] = \Delta[HbO2] + [\Delta HbR] \quad (1).$$

The wireless acquisition module consists of a microprocessor unit, a LED driving circuit, a PD amplifier and an acquisition, and a wireless transmission. The

microprocessor (MSP430, Texas Instruments, U.S.), which has the advantage of ultralow power consumption and high operation performance, is used as the microprocessor unit in this module. The wireless transmission includes a Bluetooth module with Bluetooth v2.0 compliant specification and an antenna on the Printed Circuit Board (PCB). The LED driving circuit consists of a multiplexer, operation amplifiers and NPN transistors. In the PD amplifier and acquisition unit, a 20M transresistance amplifier is designed to convert the PD current into a voltage signal, and a low-pass filter for reducing high frequency noise. Then the amplified PD signal will be digitized by an analog-to-digital converter (ADC) established in a microprocessor unit. After digitizing PD signal, the microprocessor unit can compute $\Delta[HbO2]$ and $[\Delta HbR]$ with modified Beer-Lambert law and transmit the results to the host system wirelessly via Bluetooth. The wireless signal acquisition module operates at 100 mA, and it can operate for over 10 hours with a 3.7-V 1100-mAh lithium battery. Figure 1 (b) is shown as the size of the wireless signal acquisition module. It is about 40 mm x 29 mm x 5 mm.

B. Experiment design for traumatic brain injury

We use Adult male Sprague Dawley rats to implement this experiment. The weights of those rats are 375 ± 25 g. For reducing discomfort to animals during surgery and recovery periods, all experimental procedures were agreed with the guidelines of National Institute of Health, Taiwan. Moreover, all experimental procedures were approved by Use Committee of Chi-Mei Medical Center and Animal Care. The rats were randomly assigned to three groups under the fluid percussion injury experiment with different impacts (1.6 atm,2.0 atm, and 2.4 atm) using the NIRS system.

The fluid percussion injury (FPI) experiment was used as the rat model for the TBI [14]. Before the FPI experiment, we anesthetized the rat first. Then the head of the rat was put in a stereotaxic frame. For fixing its head tightly, the ear bars were inserted into its ears. A rectal temperature probe with the thermostatic controller was plugged in the colon of the rat to keep the rat core temperature at 37°C. In order to attack the rat brain directly, a hole on the skull was drilled to expose the rat brain. The hole was located at the anterior-posterior -3 mm and lateral +4 mm from the bregma. Then a pendulum struck the reservoir to generate a fluid wave to attack the rat brain and form fluid percussion injury. For Group 2, LDF was used to monitor CBF in the injured region of the subject. The probe of LDF was located at anterior-posterior -0.8 mm and lateral +4 mm from the bregma, and was installed on the stereotaxic frame.

Before the FPI experiment, the changes of 30-second HbO_2 and HbR were recorded as the data baseline. After the FPI experiment, the rat was removed from the FPI device, and treated to help its respiration. Then, the HbO_2 and HbR changes of the brain-injured rat were monitored for 2 hours continuously. After all experimental procedures, the connector and the acrylic on the rat head were removed. In the end, we sutured the incisions on the rat with surgical wound sutures.

Repeated-Measure ANOVA was used to analyze the physiological data from this experiment for understanding the differences between different times and different groups. All experiment data were shown as mean ± standard error of the mean. And then significance was set as $P < 0.05$.

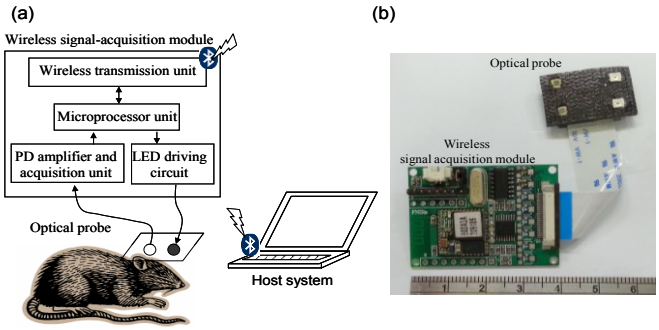

Figure 1. (a) System architecture and (b) photograph of the wireless multi-channel NIRS system.

III. RESULTS

The effect of the impact strength on the variation of cerebral blood oxygenation was first investigated. The impact strengths were set to 1.6 atm, 2.0 atm and 2.4 atm. Figure 2. shows the statistic results of the infarction volume corresponding to different impact strengths. The experimental result indicated that the higher impact strength indeed caused the larger region of the infarction volume, and it also proves that the severity of TBI experiment were under control.

In order to investigate the change of the physiological state under TBI, We used LDF to monitor the change of cerebral blood flow. Then, the variations of CBF were compared with $\Delta[HbT]$, the results were shown in Figure 3. Different from the variation of $\Delta[HbT]$, CBF increased immediately at the moment of impact, and then decreased rapidly. However, after respiration treatment, the CBF increased gradually.

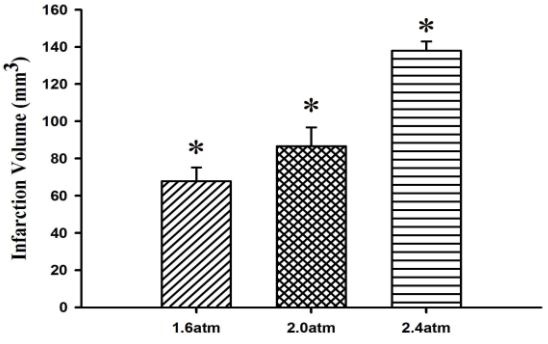

Figure 2. Infarction volume statistics after brain slices stained by TTC solution in different impact strengths (Symbol ∗ means significance, compare with the subjects of 1.6 atm impact strength).

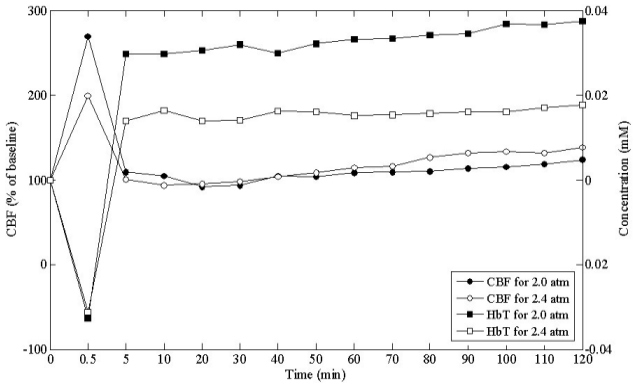

Figure 3. Temporal profiles of CBF and $\Delta[HbT]$ in ipsilateral side during and after FPI experiment.

IV. DISCUSSIONS

The outer pressure caused from the impact may directly result in the contraction of the cerebral vascular and cause the decrease of $\Delta[HbT]$ immediately. $\Delta[HbT]$ is related the cerebral blood volume (CBV) [15]. The increase of $\Delta[HbT]$ after impacting can be explained by vascular dilation and perfusion phenomenon in the presence of effective autoregulation. The concentrations of $\Delta[HbO2]$ and $\Delta[HbT]$ after impacting depend on the impact strength significantly, i.e., after impacting, the concentrations of $\Delta[HbO2]$ and $\Delta[HbT]$ trend to decrease with the increase of the impact strength. More impact strength induces more severe brain injury and causes the impairment of cerebral autoregulation.

The tendency of CBF is obviously different from that of CBV at the moment of impact. This can be explained by that the vessels in the injured region were constricted to result in the increase of local CBF, but the decease of CBV, when suffering the impact. The constriction of vessels caused the increase of blood flow velocity. After impacting, cerebral autoregulation would be induced to repair the injured region. The vessels dilated to provide enough fresh blood for the metabolism of the impaired cells or tissue. Therefore, the value of CBF reduced and even became smaller than the baseline, but the concentration change of $\Delta[HbT]$ trended to increase. Although the blood flow velocity decreased, but the cerebral blood volume still increased. Finally, we observed that CBF increased gradually, and it fits the phenomenon of increasing $\Delta[HbT]$.

V. CONCLUSION

The changes $\Delta[HbT]$ during and after TBI were investigated in this study. The concentration change of $\Delta[HbT]$ decreased immediately at the moment of impact, and increased gradually after respiration treatment. Then compared with the change of CBF measured by using LDF, the change of vessels and edema states during and after TBI can be clearly understood. Therefore, non-invasively monitoring the concentration changes of $\Delta[HbT]$ by using NIRS may be applied for evaluating the state of TBI in clinical.

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